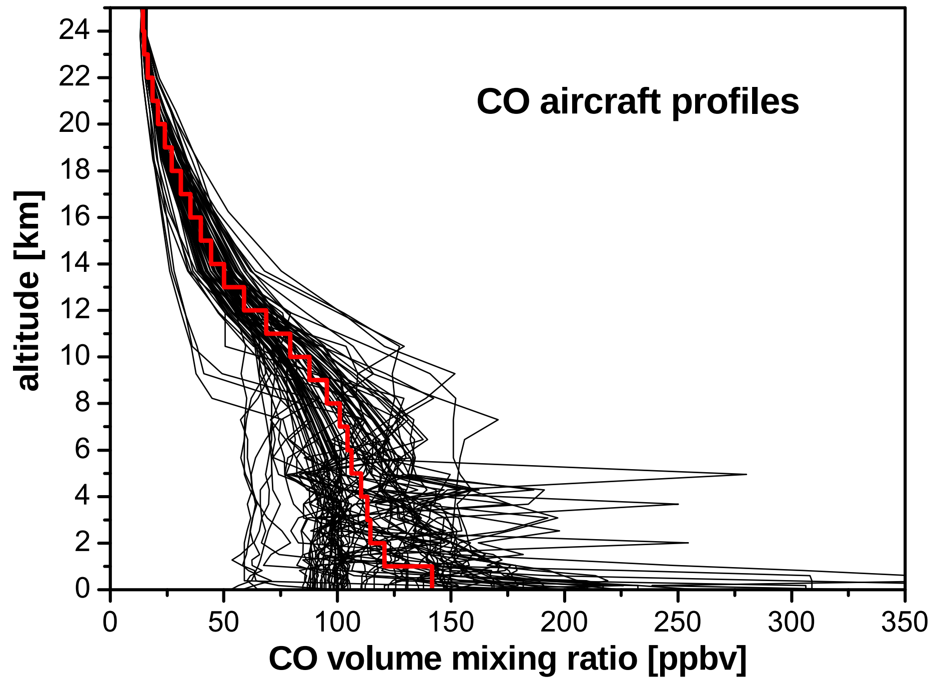
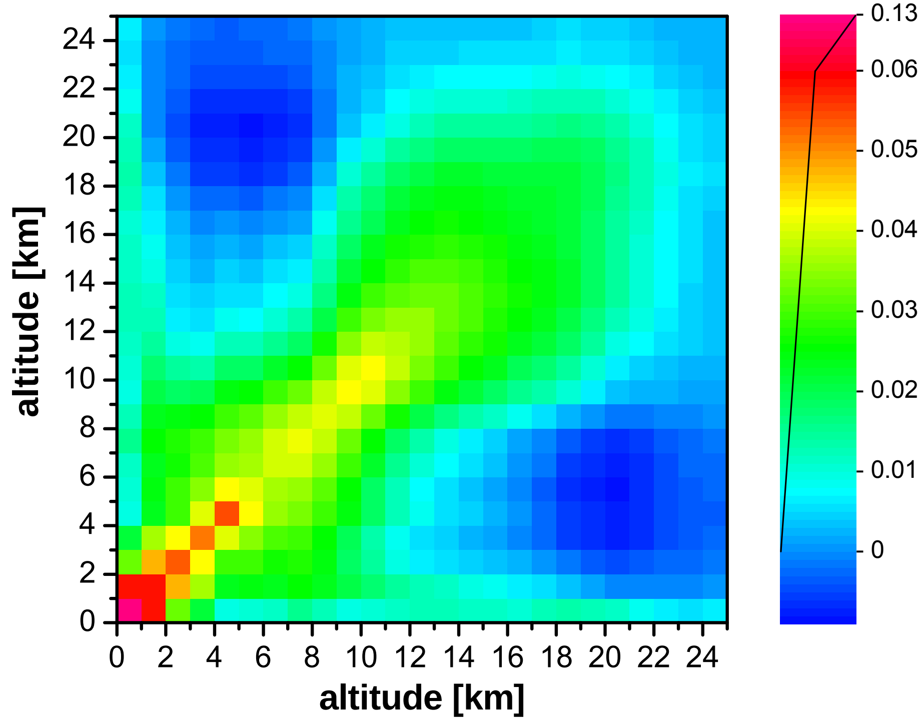
Interference errors II: Examples and error minimization

Example: standard retrieval of CO profiles

CO prior: aircraft profile ensemble
(MOPITT climatology,
47 °N ± 16 ° latitudinal band)



CO a priori
covariance



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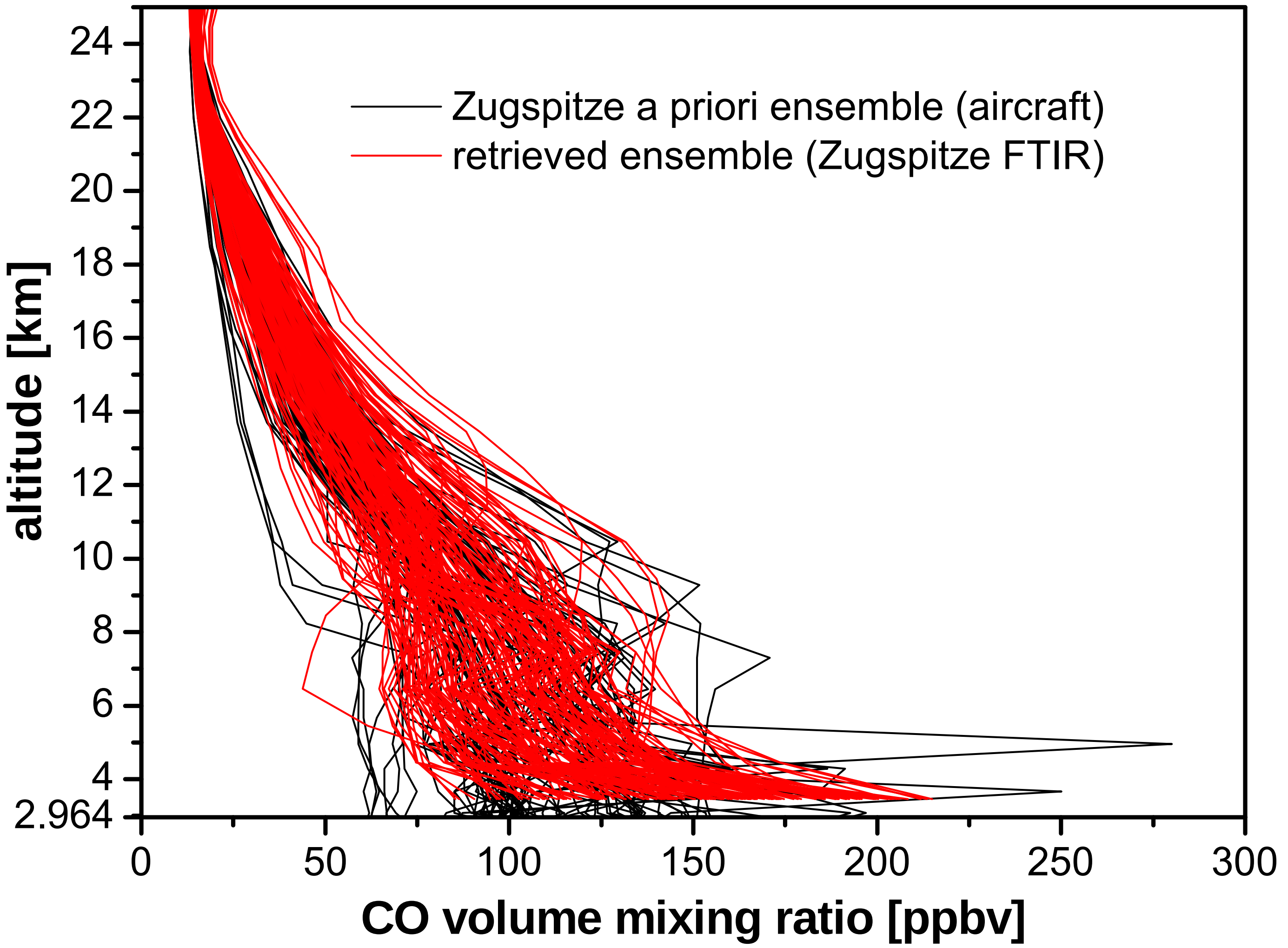
CO profiles from Zugspitze FTIR: retrieved ensemble versus prior ensemble



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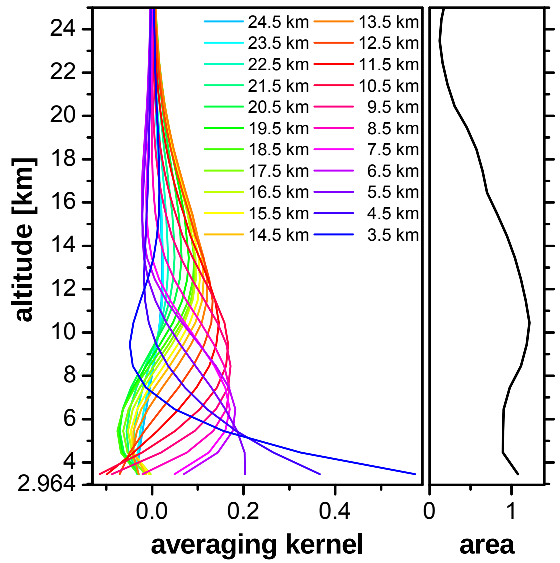
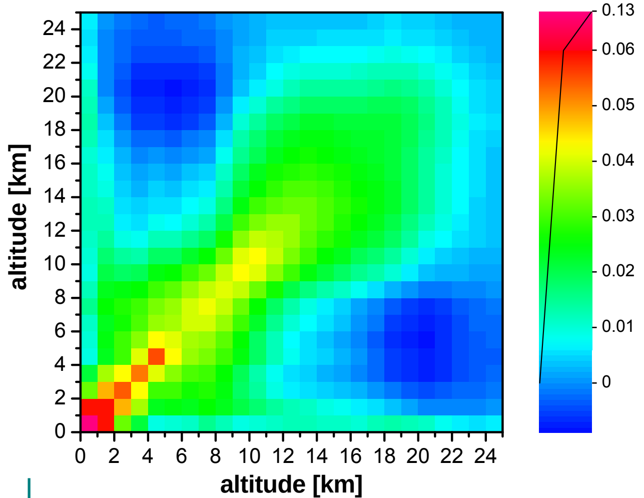
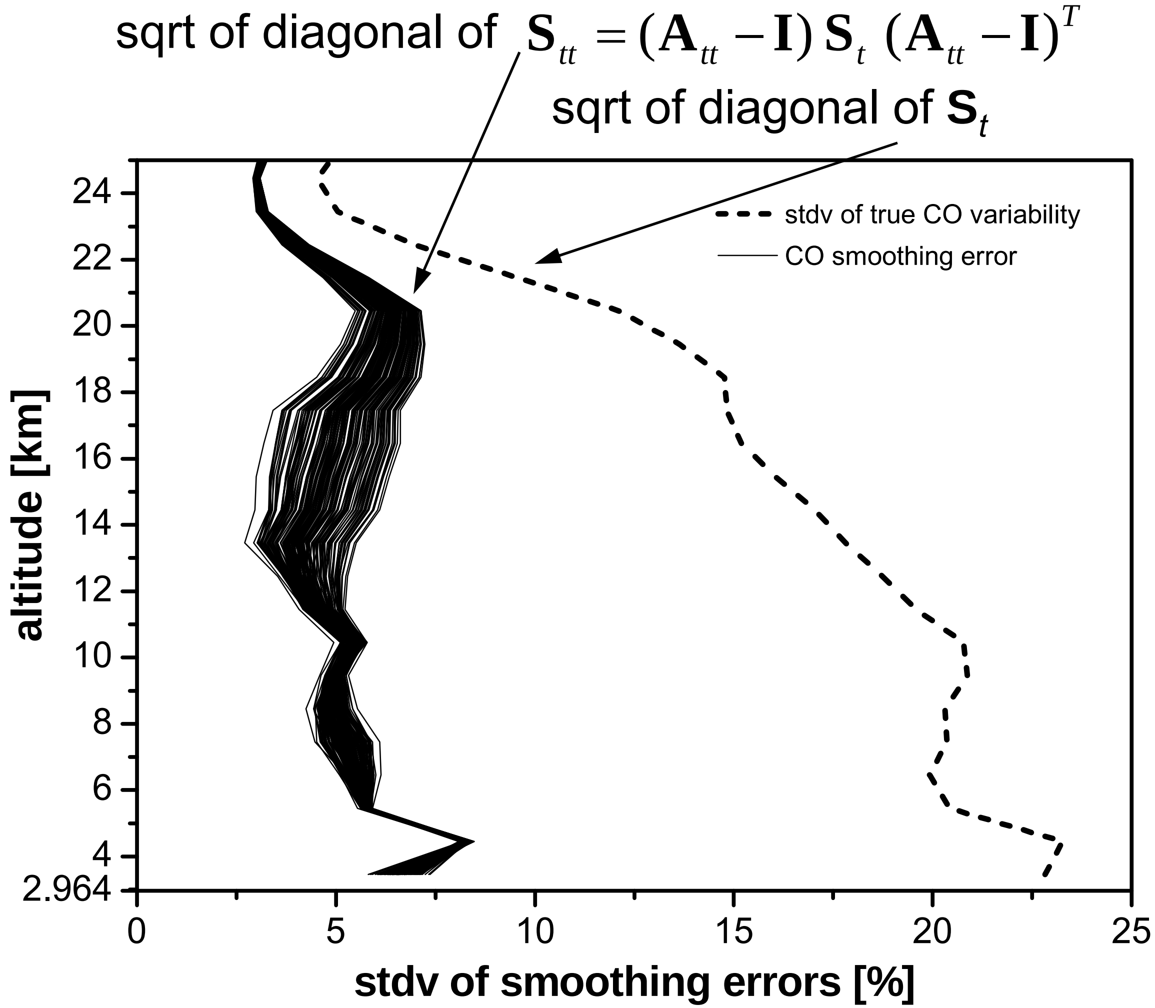
CO profiles from Zugspitze FTIR: Smoothing error



$\mathbf{A}_{tt}$



$\mathbf{S}_t$



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CO profiles from Zugspitze FTIR: Interference error calculation

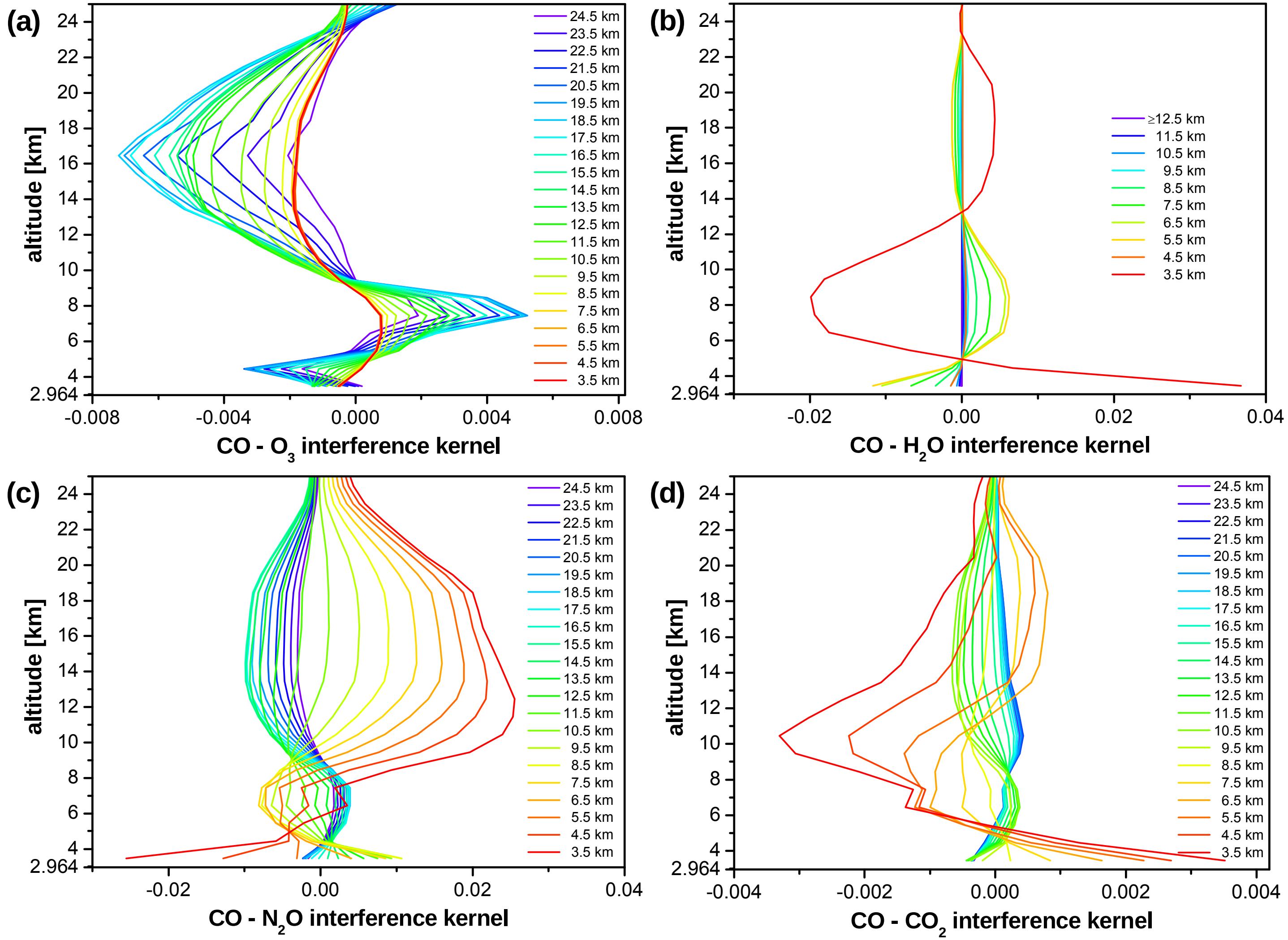
have to calculate interference error covariances

$$\mathbf{S}_{tv1} = \mathbf{A}_{tv1}\,\mathbf{S}_{v1}\,\mathbf{A}_{tv1}^{T}$$

$$\mathbf{S}_{tv2} = \mathbf{A}_{tv2}\,\mathbf{S}_{v2}\,\mathbf{A}_{tv2}^{T}$$

$$\vdots$$

CO profiles from Zugspitze FTIR: Interference kernels



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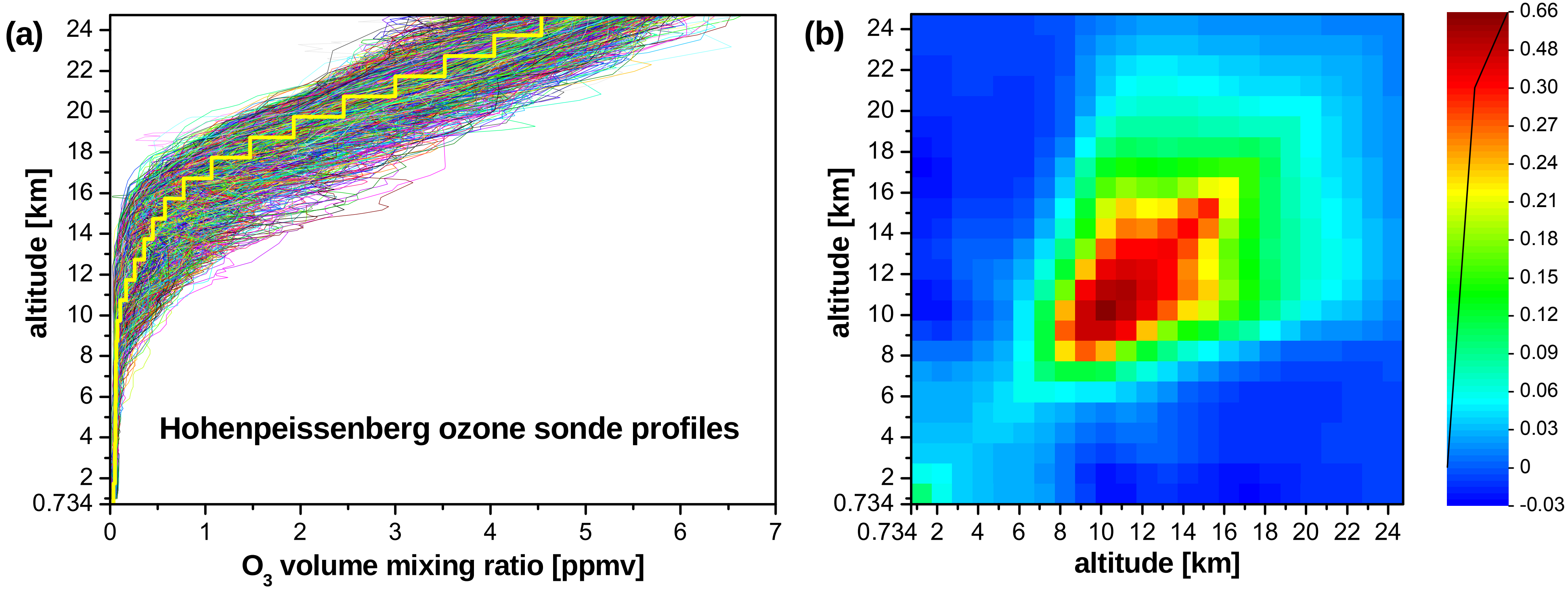
Interference errors on CO profiles: Climatological O_3 covariance



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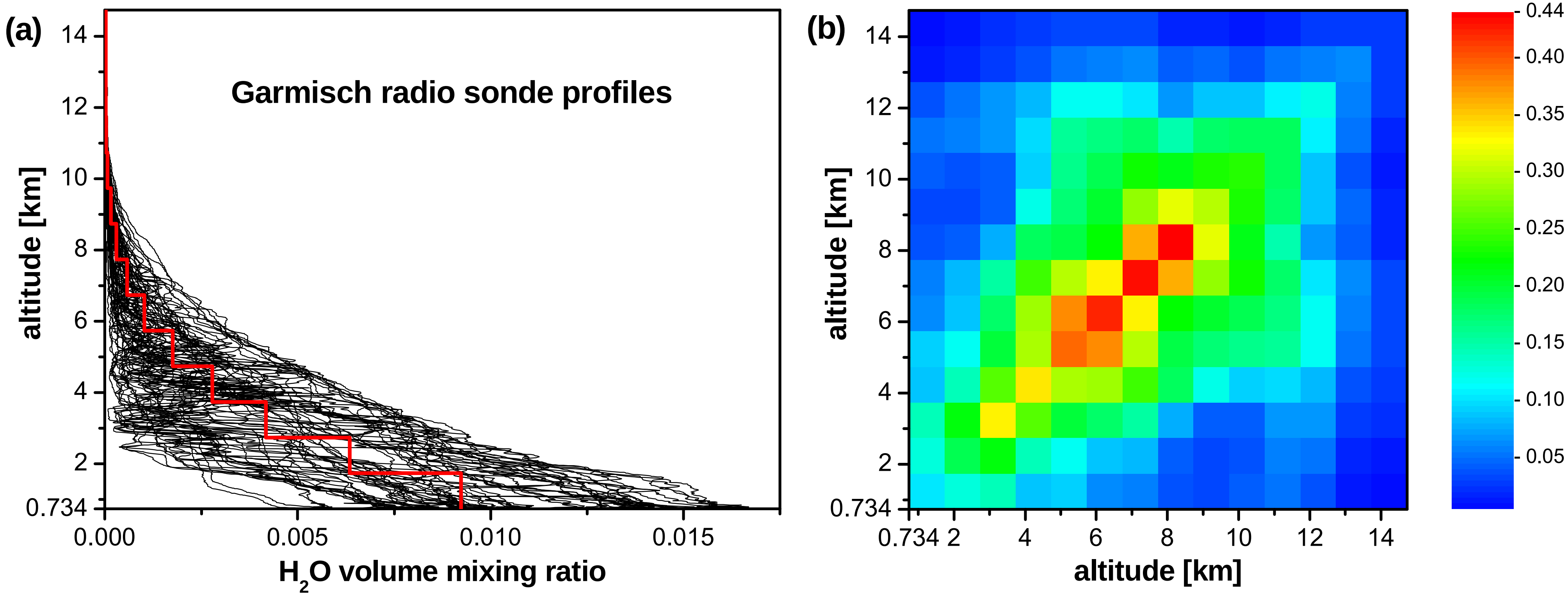
Interference errors on CO profiles: Climatological H_2O covariance



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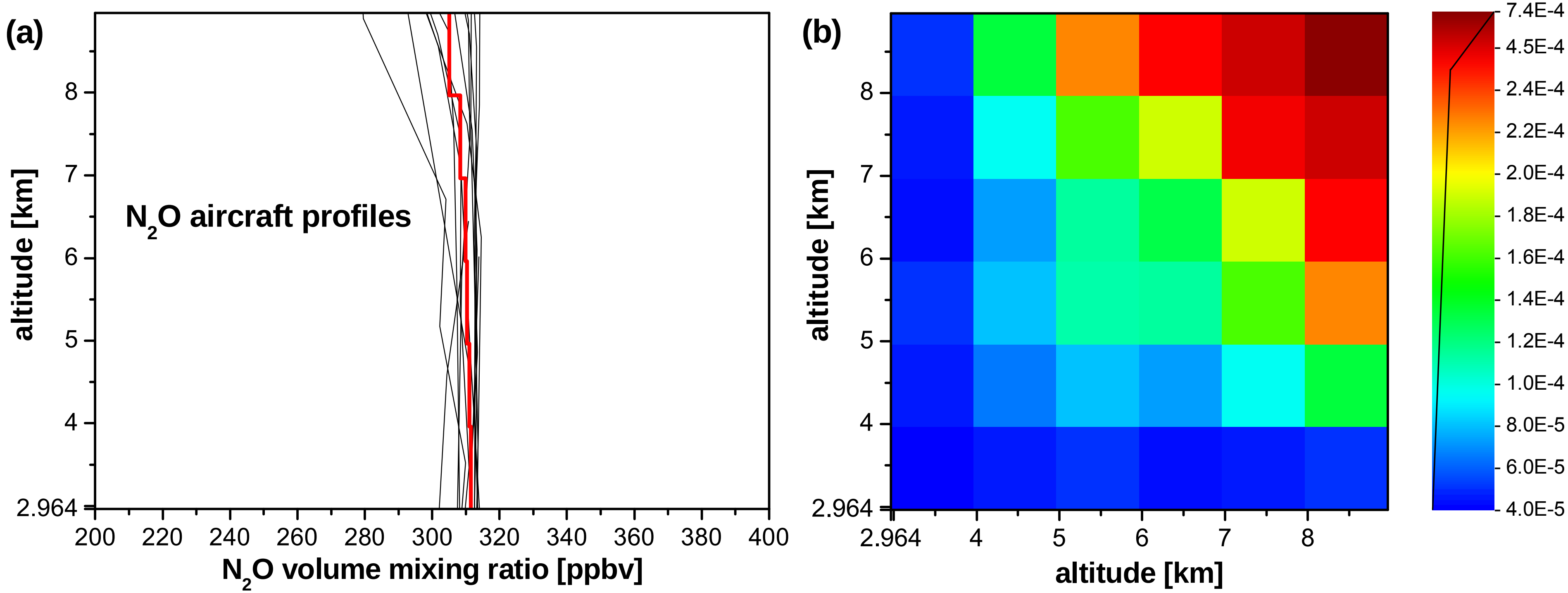
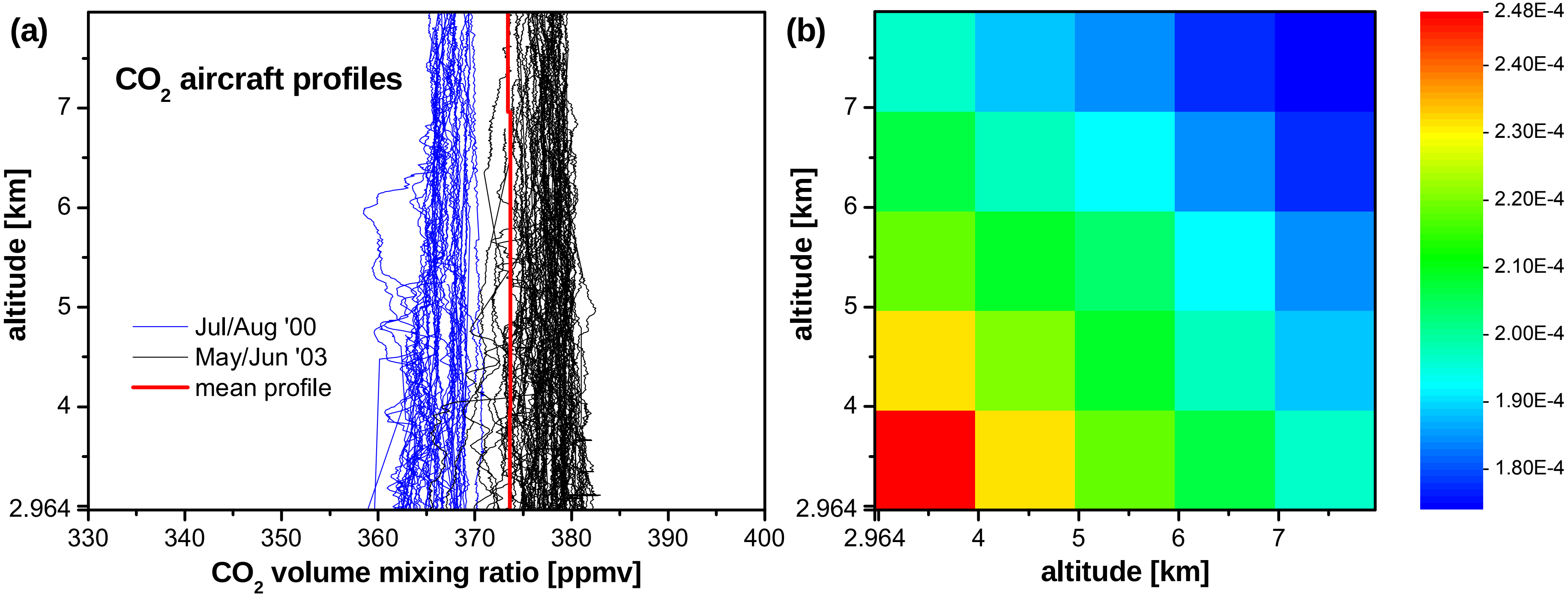
Interference errors on CO profiles: Climatological N_2O covariance



ETHmeg data base [http://www.megdb.ethz.ch/dbaccess.php]

Interference errors on CO profiles: Climatological CO_2 covariance



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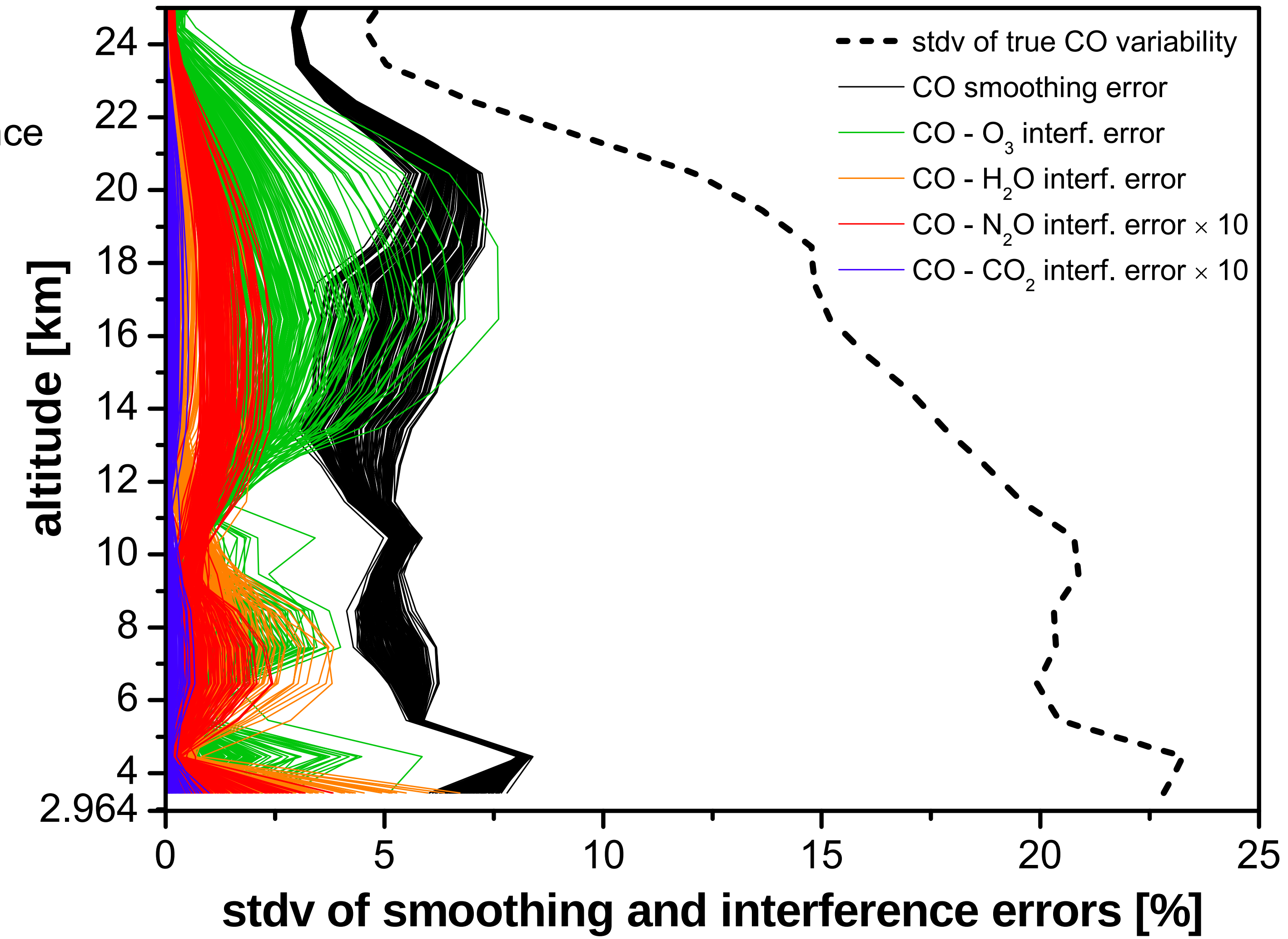
Interference errors on CO profiles: Standard Rinsland retrieval strategy

sqrt of diagonals of interference error covariance

$$\mathbf{S}_{tv1} = \mathbf{A}_{tv1}\,\mathbf{S}_{v1}\,\mathbf{A}_{tv1}^{T}$$

$$\mathbf{S}_{tv2} = \mathbf{A}_{tv2}\,\mathbf{S}_{v2}\,\mathbf{A}_{tv2}^{T}$$

$$\vdots$$

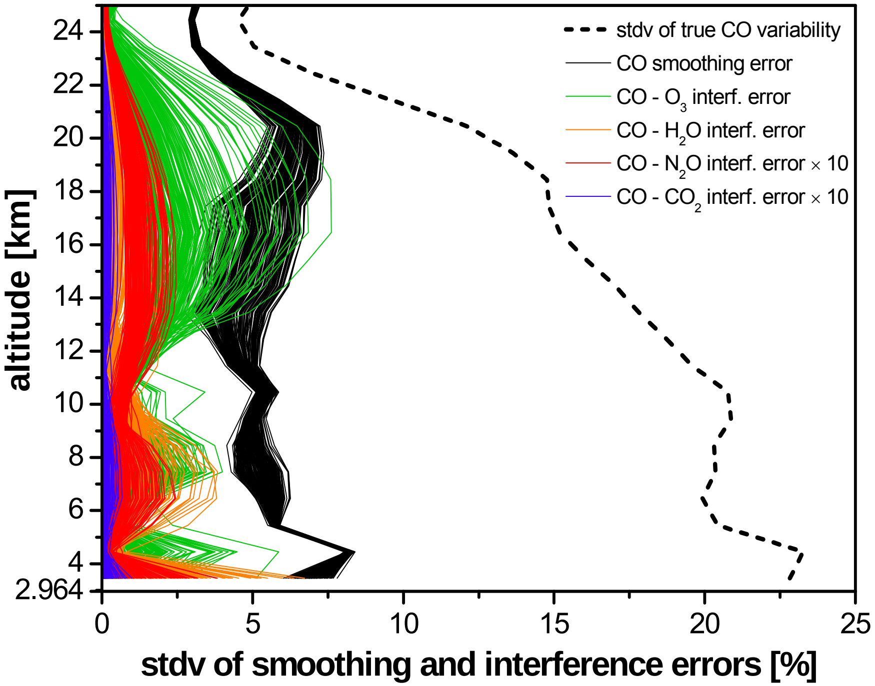


Interference errors on CO profiles: Effect of unretrieved interfering species

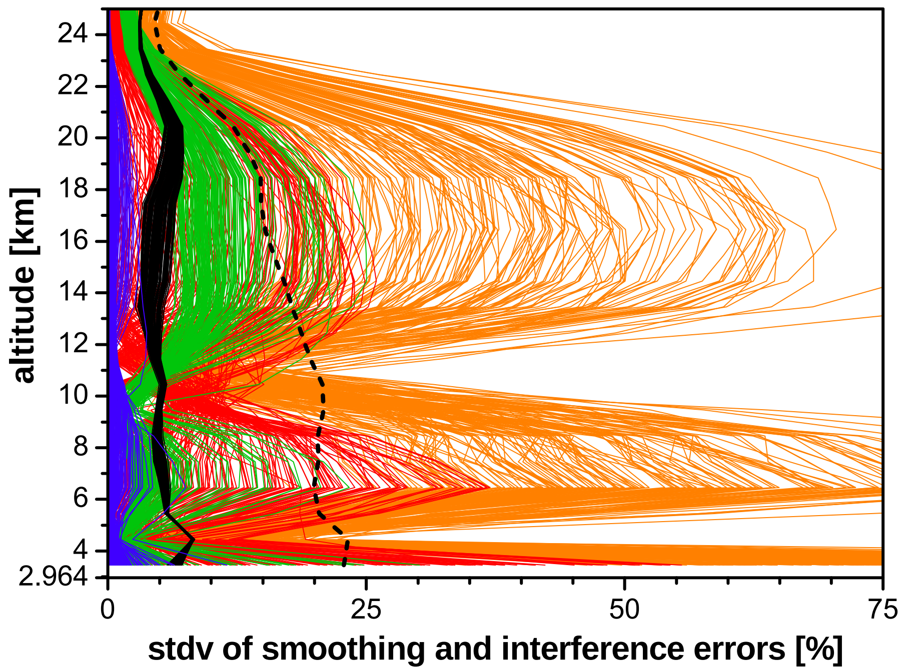
Use

$$\mathbf{R}_{dead} = \beta \times \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & 1 \end{pmatrix} \in \Re^{n \times n} \qquad \text{with } \beta \rightarrow \infty$$

Standard retrieval: scaling of interfering species



⇒ Unretrieved interfering species



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Interference errors on CO profiles: Optimum strategy for minimization

Reducing the (hard or soft) constraint applied to interfering species has two effects.

i) interference errors are strongly reduced, and

ii) the (target pecies) smoothing error is slightly increased.

Why?

ad *i*) weak constraint for interf. species avoids residuals and thereby eliminates interf. errors (at the cost of increased retrievals noise and model (parameter) error for the interf. species retrieval result, but never mind)

ad *ii*) weak constraint for retrieval of the interfering species increases the solution space for the retrieved profiles of the interfering species, which corresponds to a certain kind of deweighting in measurement space around the signature of the interfering species and around the overlapping features of the target species. This leads to a reduced information content for retrieval of the target species, i.e., an increased smoothing error

Interference errors on CO profiles: Optimum strategy for minimization

- both smoothing and interf. errors depend on the regularization strength applied to the retrieval of the interfering species,

- but with opposite sign

$\Rightarrow$ a total minimum of the combined error (from interference and smoothing) can be found for a certain regularization strength

“optimum strategy”

Optimum strategy for minimization: how to implement?

E.g., use Tikhonov L_1 for the interfering species (regularization strenght can be easily tuned via one parameter ☺):

$$\mathbf{R}_{\nu 1} = \alpha_{\nu 1} \times \begin{pmatrix} 1 & -1 & 0 & \cdots & 0 \\ -1 & 2 & \ddots & \ddots & \vdots \\ 0 & \ddots & \ddots & \ddots & 0 \\ \vdots & \ddots & \ddots & 2 & -1 \\ 0 & \cdots & 0 & -1 & 1 \end{pmatrix} \in \Re^{n \times n}$$

where $\alpha_{\nu 1}$ is the regularization strength imposed upon interfering species $\nu 1$

Interference errors on CO profiles: Optimum strategy for minimization

For performing the trade off (interference against smoothing error) as a function of α_{v1}, α_{v2}, … we also need to derive scalar error quantities from the error covariances $\mathbf{S_{tt}}$ and $\mathbf{S}_{\mathbf{t}v1}$, $\mathbf{S}_{\mathbf{t}v2}$, …

There are several ways to do this. Use, e.g., “mean errors”

$$\bar{\sigma}_{tv1}(\alpha_{v1}) := \sqrt{\sum_{i=1}^{n} (\mathbf{S}_{tv1})_{ii} / n} \quad , \quad \ldots \textit{mean interference error from speceis } v_1$$

…

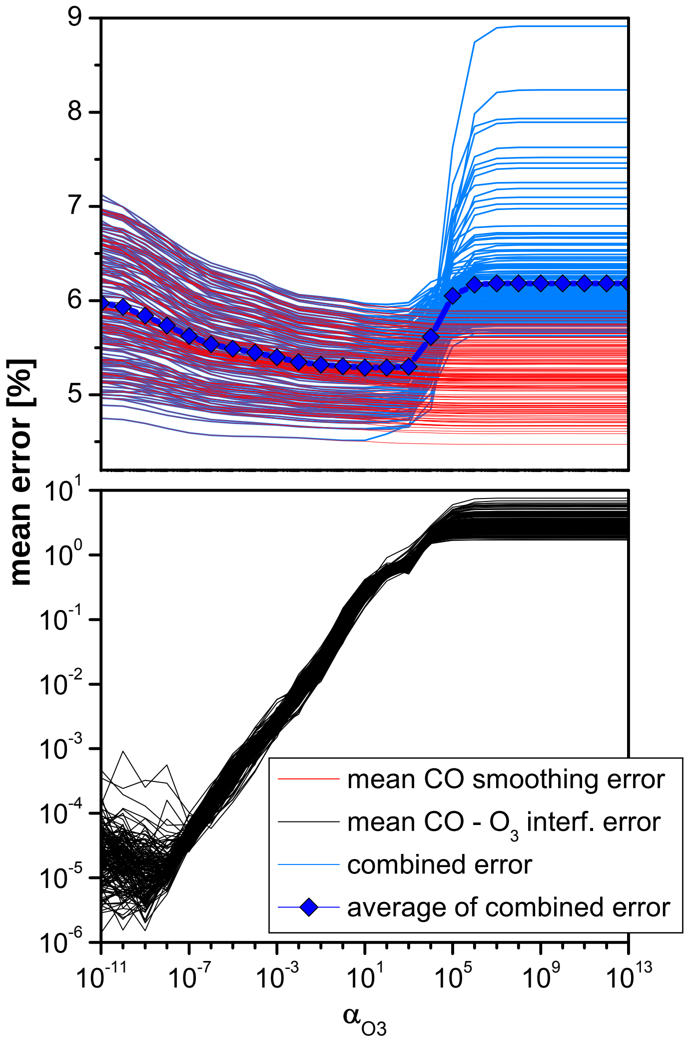
$$\bar{\sigma}_{tt}(\alpha_{v1}) := \sqrt{\sum_{i=1}^{n} (\mathbf{S}_{tt})_{ii} / n} \quad , \quad \ldots \textit{mean smoothing error}$$

(remember: both depend on α_{v1})

Interference errors on CO profiles: Optimum strategy for minimization

Search for minimum of

$$\bar{\sigma}_{comb}(\alpha_{v1}) = sqrt(\bar{\sigma}_{tt}^{2}(\alpha_{v1}) + \bar{\sigma}_{tv1}^{2}(\alpha_{v1}))$$



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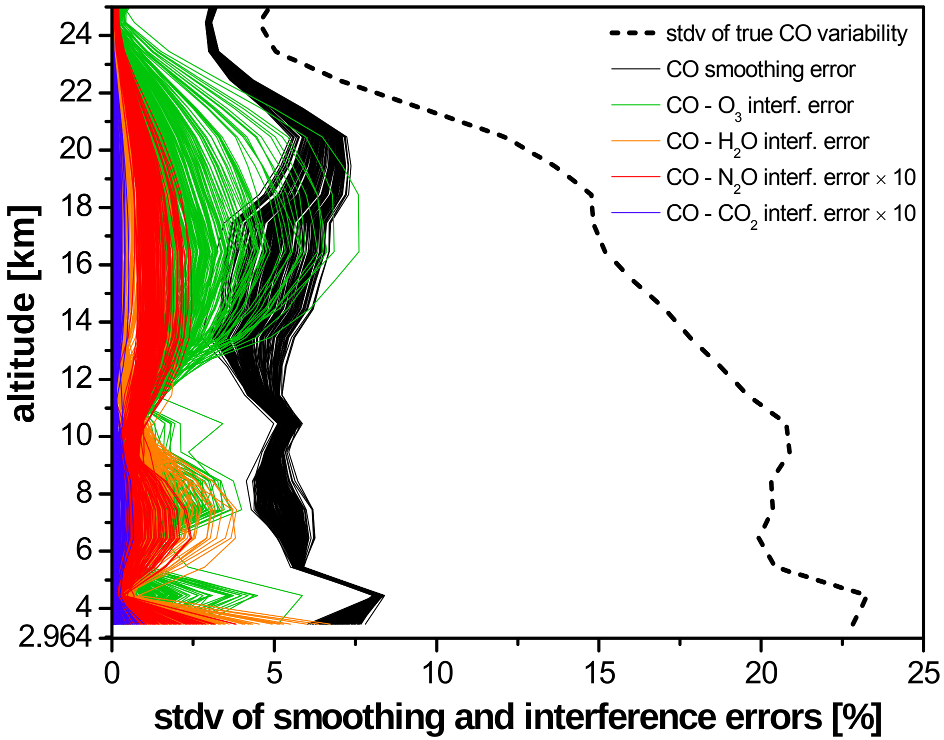
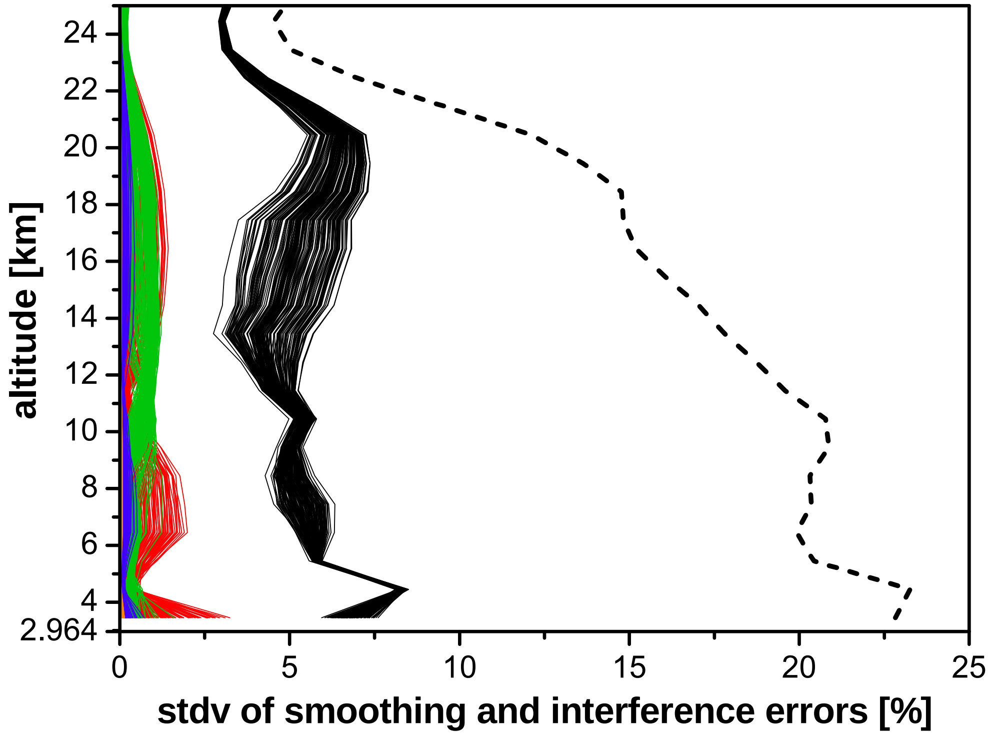
Interference errors on CO profiles: Interference error minimization

Standard retrieval: scaling of interfering species



Optimum strategy for retrieving interfering species



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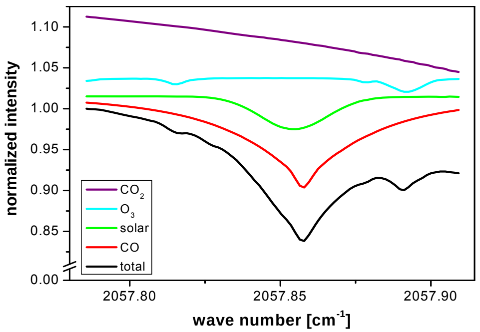
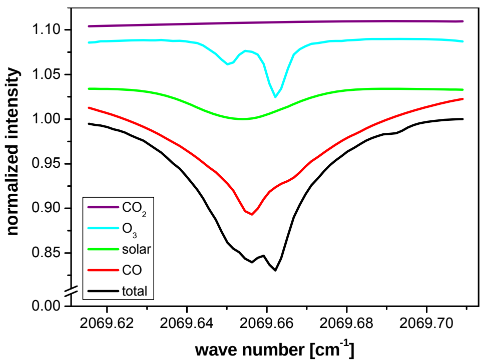
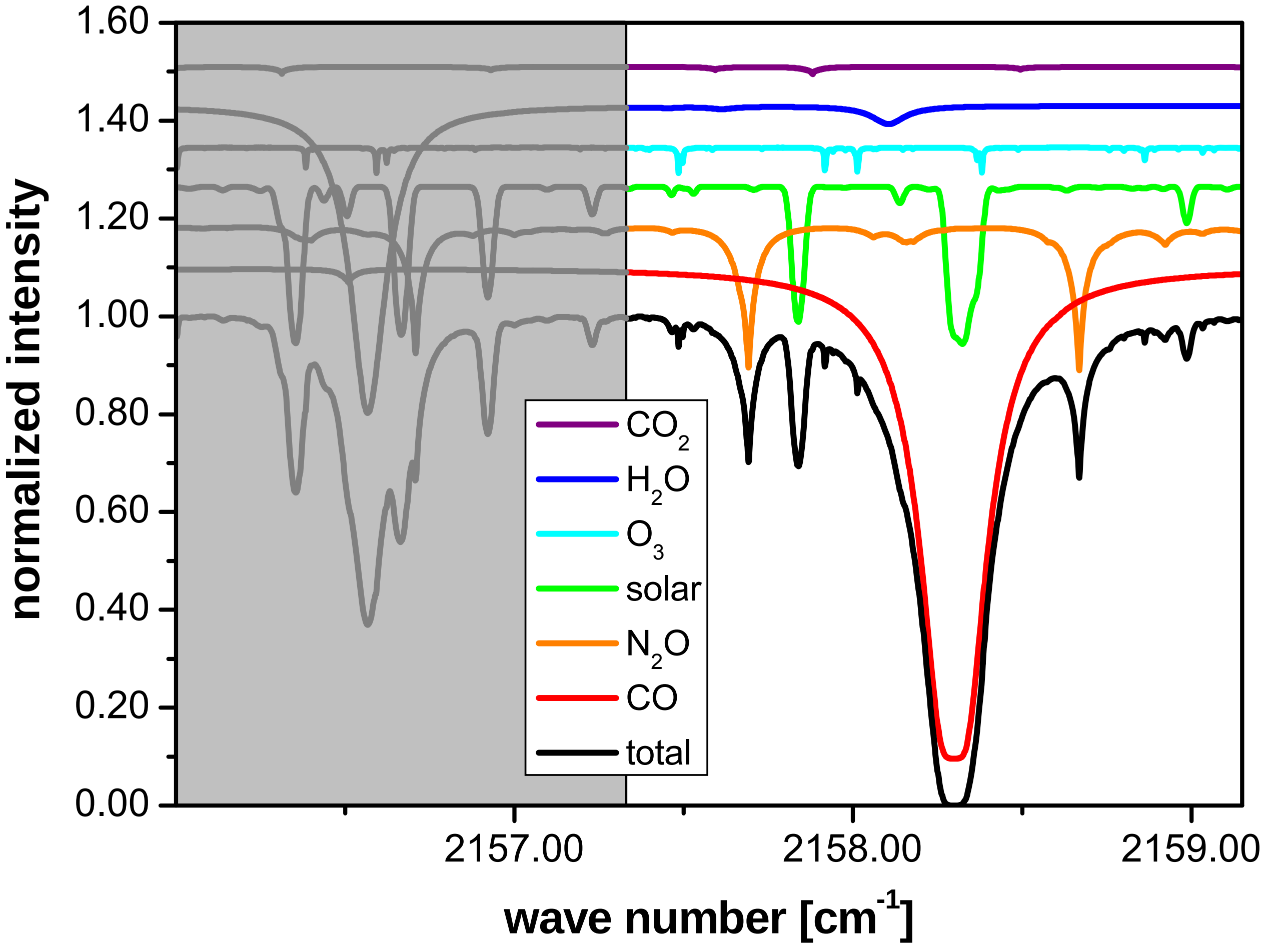
Interference errors on CO profiles: Effect of widened microwindow

Rinsland (2000) microwindows widened: strong water line included in R3 window







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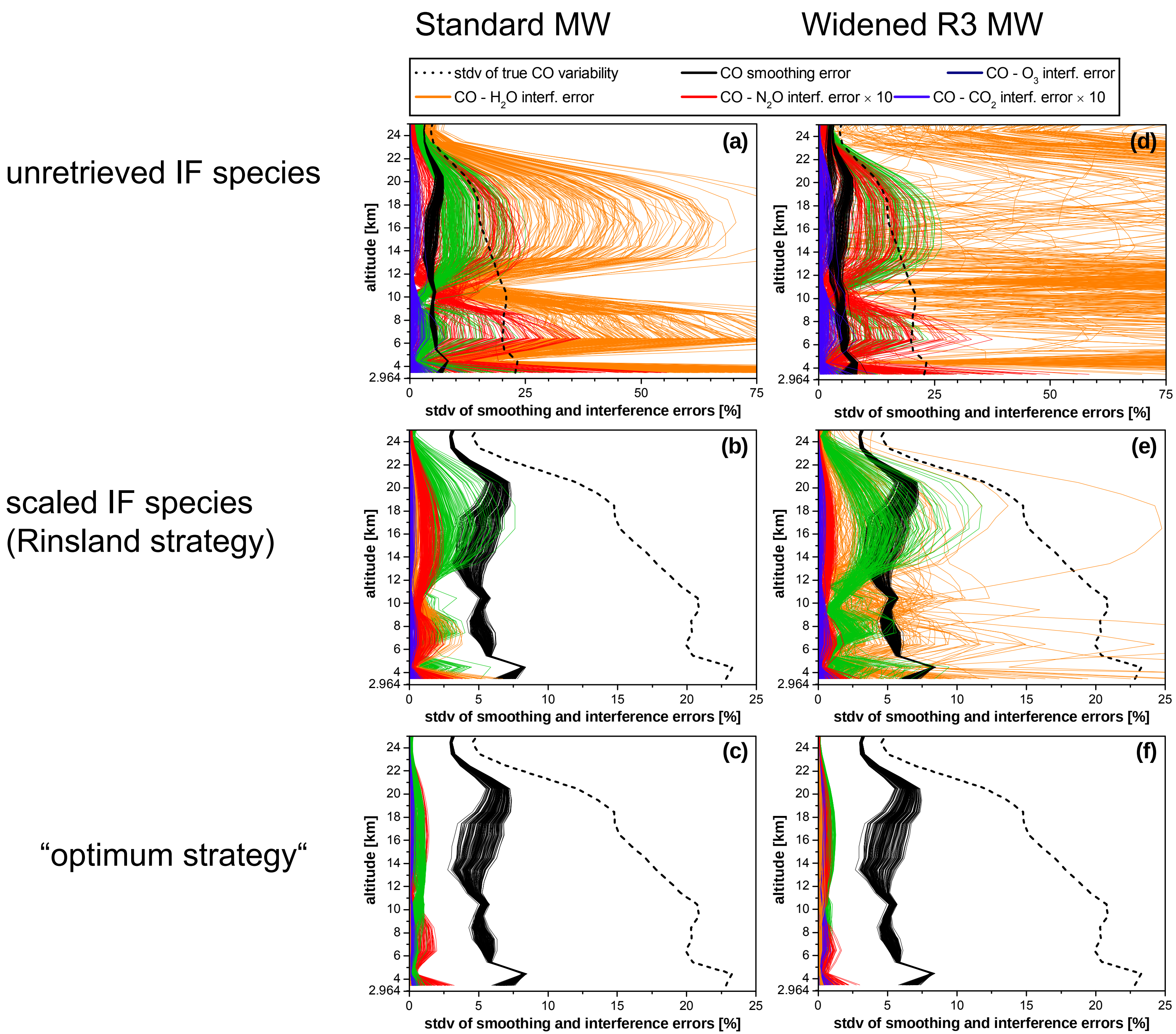

Standard MW
Widened R3 MW
stdv of true CO variability
CO smoothing error
CO - O_3 interf. error
CO - H_2O interf. error
CO - N_2O interf. error × 10
CO - CO_2 interf. error × 10
unretrieved IF species
scaled IF species
(Rinsland strategy)
“optimum strategy“
(a)
(b)
(c)
(d)
(e)
(f)
altitude [km]
stdv of smoothing and interference errors [%]

Summary (II): Examples and error minimization

• using only simple profile scaling of interfering species (as most groups do) may be not suffcient to suppress interference errors

• e.g., in CO retrievals profile scaling of the interfering species leads to interference errors that are comparable to smoothing errors and exceed smoothing errors at certain altitudes

• “optimum strategy”: joint profile retrieval of interf. species with optimized (Tikhonov-type) regularization searching for minimum overall error (smoothing & interf. errors) practically eliminates interf. errors (“species selective deweighting”)

• the target species can still be retrieved via climatological OE, if preferred

• effect of microwindow widening (example widened R3-window):

- case of unretrieved interf. species: strongly increased interf. errors

- case of scaled interf. species: increased state dependency - occasionally very high interf. errors for some (water vapor) states

- case of optimum strategy: is uncritical and even reduces overall (smooting & interference) error